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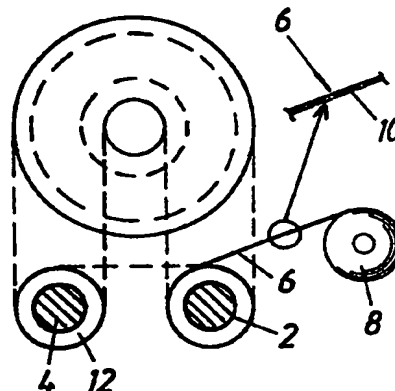
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(21) International Application Number: PCT/SE98/02157 (22) International Filing Date: 27 November 1998 (27.11.98) (30) Priority Data: 9704376-4 27 November 1997 (27.11.97) SE (71) Applicant (for all designated States except US): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE). (72) Inventors; and (75) Inventors/Applicants (for US only): SCHÜTTE, Thorsten [SE/SE]; Bangatan 5 B, S-722 28 Västerås (SE). SASSE, Christian [DE/SE]; Drottninggatan 4 B, S-724 64 Västerås (SE). HOLMBERG, Pär [SE/SE]; Haga Parkgatan 6 C, S-721 78 Västerås (SE). FROMM, Udo [DE/SE]; Liegatan 33, S-724 67 Västerås (SE). (74) Agents: HOPFGARTEN, Nils et al.; L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published Without international search report and to be republished upon receipt of that report.

(54) Title: SHELL TRANSFORMER/REACTOR

(57) Abstract

A shell transformer/reactor comprises at least one electric winding (4) surrounded by a shell (12) of magnetizable material. The electric winding comprises a high voltage cable arranged to substantially enclose the electric field generated by a current in the winding. By a method for producing such a shell transformer/reactor, the electric winding (4) is wound in a support construction (2).



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SHELL TRANSFORMER/REACTOR

The present invention is related to a shell transformer/reactor comprising at least one electric winding surrounded by a shell of magnetizable material and a method for producing such a transformer/reactor.

Transformers are involved in all transmission and distribution of electric energy, and their purpose is to admit exchange of electric energy between two or more systems. Transformers are available in all effect ranges from the VA range up to the 1000 MVA range. There is a spectrum of transformers for voltages up to the highest transmission voltages used today.

The transformers to which the present invention is related are so-called power transformers of shell type with a rated effect from a couple of hundreds of kVA up to more than 1000 MVA with rated voltages from 3-4 kV and up to transmission voltages of 800 kV.

The winding is wound around the core in a usual toroidal transformer. Difficulties will, however, arise if a large such toroidal transformer is to be made due to the fact that each turn of winding is to pass the narrow space in the middle of the core. This problem does not exist for shell transformers.

Shell transformers are previously known from for example DE 40410. These previously known transformers comprise windings of copper wires surrounded by an iron core, which is formed by iron wire, iron band or iron sheet.

The object of the present invention is to provide a shell transformer for the above mentioned effect and voltage ranges, which is easy to produce, as well as a corresponding reactor of shell type. A further object of the invention is to propose a method for producing such a transformer/reactor.

These objects are achieved with a shell transformer/reactor of the type described in the introductory portion with the characterizing

features set forth in claim 1 and with a method with the characterizing features defined in claim 26.

Since the electric winding comprises a high voltage cable, which is arranged to substantially enclose the electric field generated by a current in the winding, the production of the shell transformer/reactor is greatly facilitated since the shell can be designed without having to consider this electrical field.

The cable used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847.

Additional descriptions of the cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Accordingly, the windings of the transformer/reactor according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type today used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such cables comprise an inner conductor composed of one or more strands, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this inner semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology of the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature of the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each

other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers
5 consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in the radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion of the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers
10 being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity
15 within the range of 10^{-1} - 10^6 ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl
20 pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or
25 metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention.
30 The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

5 Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be of substantially the same order of magnitude. This is the case with the combination of the materials listed above.

10 The materials listed above have relatively good elasticity, with an E-modulus of $E < 500$ MPa, preferably < 200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in
15 the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.
20

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.
25

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

According to a preferred embodiment of the transformer/reactor according to the invention, the transformer/reactor is produced by winding the shell from a band of the magnetizable material covered with glue or paste whereby a mechanically stable shell and an easy and robust transformer or reactor construction is obtained. The terms "glue" or
30

"paste" are in this application used for a somewhat "adhesive" covering keeping superposed turns of winding together. The covering may either be formed by a polymeric material maintaining the adhesive consistence, such as of ordinary tape, or preferably be formed by a material, which in some way is cured, for example by heating so that a more rigid construction is obtained. The production of the shell will be uncomplicated by covering one of the surfaces of the band with glue or paste in advance. Further, the winding band for the core does not need to be continuous, since the magnetic flux can pass an air or glue gap. It is, thus, possible to wind the shell band until the end of the band roll in question and thereafter continue the winding with the next roll without putting down any big effort in bringing the free band ends into contact with each other. A relatively thin band is also easy to bend and, if necessary, fold for the shell production.

According to an advantageous embodiment of the transformer/reactor according to the invention, the glue or paste comprises a magnetizable filling agent, such as iron powder or magnetite powder. The reluctance of the core is thereby reduced.

According to preferred embodiments of the transformer/reactor according to the invention, the second semiconducting layer of the insulated conductor in the windings is arranged to form substantially one equipotential surface surrounding the conductor, and the second semiconducting layer may be connected to a predetermined potential, suitably ground potential. This is an important advantage, as metallic components in, for example, power transformers normally have a set ground potential.

According to other preferred embodiments of the transformer/reactor according to the invention, at least two adjacent layers of the winding of the transformer/reactor have substantially equal coefficients of thermal expansion and each of said three layers of the insulated conductor in the windings are in contact with adjacent layers along substantially the entire surfaces turned to each other. The different layers of the insu-

lated conductor contact each other also when the cable is bent, which results in that ruptures are avoided when producing the winding. Ruptures resulting from thermal expansion are also avoided.

5 According to a further advantageous embodiment of the transformer/reactor according to the invention, the winding is surrounded by a support construction. This support construction serves as a support for the band at the beginning of the winding of the shell.

10 According to still another advantageous embodiment of the transformer/reactor according to the invention, the support construction and the shell are torus-shaped. A transformer/reactor is in this way obtained with a nearly perfect symmetry, which results in that practically no magnetic leak flux. Such an embodiment is therefore particularly well suited for being used in environments where any kind of disturbances should be avoided or in environments where it is desirable to avoid
15 subjecting persons to electromagnetic fields.

According to a further preferred embodiment of the transformer/reactor according to the invention, two adjacent openings are formed through the shell for supply and removal of a cooling medium and a perforated partition for passage of the winding cable wall is arranged
20 between the openings substantially across the winding space inside the shell. An easy embodiment for supply of the cooling medium is thereby achieved, and it is avoided that the cooling medium flows the "shortest distance" within the shell from the inlet to the outlet opening by the arrangement of the partition wall. The cooling medium is instead forced to
25 pass through substantially the complete winding space in the shell and an effective cooling is thereby achieved.

According to an advantageous embodiment of the method according to the invention, pins or blocks are arranged in a direction through the shell to be formed at the winding of the shell at those positions
30 where openings through the shell are desired for electrical through-conductions and cooling tubes, whereupon the band of magnetizable material is wound at the side of said pins or blocks, and the pins or blocks

are thereafter removed. The opening formed by the pins or blocks will remain. It is, thus, in this way possible to obtain openings of a desired shape and on desired positions running through the shell.

5 According to another advantageous embodiment of the method according to the invention, the primary and secondary windings of the transformer are wound mixed with each other. The advantage is thereby achieved that the magnetic field within the shell will be at a minimum level with a low stray inductance as a consequence thereof.

10 Preferred embodiments of the shell transformer/reactor according to the invention will now be described more closely referring to the appended drawings in order to explain the invention more in detail. In the drawings:

- Fig. 1 is a cross-section view of the insulated conductor or cable used for the windings of the transformer/reactor according to the invention,
- 15 Fig. 2 shows a torus-shaped transformer/reactor according to the invention in a view from above as well as in a section across the torus in order to illustrate the production of the shell,
- Fig. 3 shows an alternative embodiment of the torus-shaped shell transformer/reactor in fig. 2, provided with openings through the shell for electrical through-connections and supply and removal of a cooling medium, and
- 20 Fig. 4 is a section through an alternative embodiment of the transformer/reactor in fig. 3.

25 The windings of the shell transformer/reactor according to the invention comprise a high voltage cable or insulated conductor, which is adapted to enclose the electric field in itself. Fig. 1 illustrates an example of such a cable 11 in a cross-section, the cable comprising a number of strands 35 of, for example copper, with a circular cross-section.

30 These strands 35 are provided in the middle of the cable 11. A first semiconducting layer 13 is arranged around the strands 35. An insulation layer 37, for example of XLPE-insulation, is arranged around the

first semiconducting layer 13. A second semiconducting layer 15 is arranged around the insulation layer 37. The insulated conductor has a diameter in the interval 20-250 mm and a conducting area in the interval 80-3000 mm².

5 The illustrated insulated conductor is flexible and this property is maintained during the whole lifetime of the conductor. The different layers are contacting each other also when the cable is being bent and at least two adjacent layers have substantially equal coefficients of thermal expansion in order to avoid ruptures between the layers when the cable
10 is subjected to thermal expansion.

Fig. 2 illustrates a torus-shaped transformer/reactor according to the invention. The winding or the windings 4 is/are arranged within a torus-shaped tube 2 of an insulating material, such as a plastic material. These windings 4 are wound by the cable 11 shown in fig. 1. The pri-
15 mary and secondary windings may be mixed in the case of a transformer, the fields from the windings thereby advantageously reducing or almost extinguishing each other.

The tube 2 serves as a support for the band 6, utilised for the production of the shell. This support construction does not necessarily
20 need to be in the form of a tube, but may also have other forms, such as a grate construction.

The shell of the transformer/reactor is wound by a band 6 of a magnetizable material. The band 6 is covered or impregnated with a glue or paste, for example a curable resin on at least one of the sides
25 thereof, so that a self-adhesive band is obtained. Adjacent winding turns will thereby be glued together so that a mechanically rigid and stable shell is obtained. Such a gluing together of the turns is necessary, especially for production of large transformers/reactors.

The band from which the shell is wound does not need to be continuous along the complete length thereof, since the magnetic flux can
30 pass an air or glue gap. The shell may therefore be wound from a band roll 8, the winding continuing until the roll 8 is finished, the winding

thereafter continuing from a new roll without any requirements of a secure joining of the two free band ends. The production of the shell is in this way facilitated.

5 The glue or paste 10 comprises a magnetizable filling agent, such as iron powder or magnetite powder, in order to reduce the reluctance of the shell.

The band 6 is preferably made of a thin iron band, which is easy to bend and fold for the production of the shell.

10 Openings may easily be provided through the shell 12 for electric connections and supply and removal of cooling medium in the transformer/reactor according to the invention. By arranging a hollow construction of a desired shape in the middle of the transformer/reactor, a corresponding shell may be formed by winding onto this construction. Blocks or pins of, for example, wood are suitably arranged in the direction
15 through the shell to be formed at those positions where openings are desired through the shell, whereupon the band is wound at the side of said pins or blocks, the pins or blocks thereafter being removed so that the openings are set free. The electric winding or windings may in advance be arranged inside the hollow construction or the hollow construction may also be formed such that the cable for the electric winding or
20 windings may be rolled in through the above mentioned openings to the space inside the construction.

Fig. 3 illustrates such openings on the upper side of the transformer/reactor at 14 and on the lower side of the transformer/reactor at 16.

25 Four electrical through-connections are required through the shell in the most simple case of a transformer with one primary and one secondary winding and two electrical through-connections are required through the shell in the case of a reactor with only one winding. The cooling medium may also be supplied and removed from the openings
30 14, 16, see arrows in figs. 3 and 4. The cooling medium may be air, a liquid or a cryo-liquid, such as liquid nitrogen or CO₂. Tubes may be arranged inside or in parallel with the insulated conductor in the winding 4

for the cooling, the cooling medium being conveyed through said tube/tubes. The cooling medium may alternatively be allowed to flow freely inside the winding space inside the shell.

5 An alternative embodiment is illustrated in fig. 4 in a section parallel to the plane of the paper through the torus-shaped transformer/reactor illustrated in fig. 2 with two adjacent openings 18, 20 through the shell 12 for supply and removal of the cooling medium. A partition wall 22 is arranged across the winding space between the two openings 18, 20 in order to avoid that the path of the cooling medium is being "short-circuited" by that the cooling medium flows the shortest path from the inlet 18 to the outlet 20. The cooling medium is in this way forced to flow substantially the complete turn around the winding space from the inlet 18 before it reaches the outlet 20. An effective cooling is thereby obtained. The partition wall 22 is perforated in order to allow passage of the cable of the winding or the windings 4.

10 The figs. 2-4 illustrate torus-shaped transformers/reactors. There is, thanks to their perfect symmetrical form practically not generated any leak field at all. These embodiments are therefore particularly well suited for being used in environments where it is desirable to avoid disturbances or where it is desirable to avoid subjecting persons to electromagnetic fields as mentioned above.

20 Obviously the transformer/reactor according to the invention may have another shape, for example a square shape, which, however, would result in some leak flux.

25 The above described embodiments of the transformer/reactor according to the invention are one-phase embodiments. Several transformers/reactors may, however, according to the invention easily be arranged to jointly form a multi-phase transformer/reactor. A plurality of transformers/reactors may, for example, be arranged on a common axis.

CLAIMS

1. A shell transformer/reactor comprising at least one electric winding (4) surrounded by a shell (12) of magnetizable material, **character-**
5 **ized** in that the electric winding (4) comprises a high voltage cable, which is arranged to substantially enclose an electric field generated by a current in the winding
2. A transformer/reactor according to claim 1, **characterized** in that
10 the cable comprises at least one electric conductor (35), a first layer (13) with semiconducting properties surrounding the conductor, an insulating layer (37) surrounding the first layer, and a second layer (15) with semiconducting properties surrounding the insulating layer.
3. A transformer/reactor according to claim 2, **characterized** in that
15 the potential of the first layer (13) is substantially equal to the potential of the conductor (35).
4. A transformer/reactor according to claim 2 or 3, **characterized** in
20 that the second layer (15) is arranged to form substantially one equipotential surface surrounding the conductor (35).
5. A transformer/reactor according to claim 4, **characterized** in that
25 the second layer (15) is connected to a predetermined potential.
6. A transformer/reactor according to claim 5, **characterized** in that
said predetermined potential is ground potential.
7. A transformer/reactor according to any of the claims 2-6, **charac-**
30 **terized** in that at least two adjacent layers (13, 37, 15) of the winding (14) of the transformer/reactor have substantially equal coefficients of thermal expansion.

8. A transformer/reactor according to any of the claims 2-7, **characterized** in that the conductor comprises a number of strands (35) and that at least some of the strands are in electrical contact with each other.

9. A transformer/reactor according to any of the claims 2-9, **characterized** in that each of said three layers (13, 37, 15) is rigidly connected to adjacent layers along substantially the entire contacting surface.

10. A transformer/reactor according any of the preceding claims, **characterized** in that said layers are formed by materials with such elasticity and coefficients of temperature expansion that volume changes of the layers caused by temperature variations during operation are absorbed by the elasticity of the materials so that the contact of adjacent layers is maintained.

11. A transformer/reactor according to any of the preceding claims, **characterized** in that the materials in the layers have a high elasticity.

12. A transformer/reactor according to any of the preceding claims, **characterized** in that the cable is flexible.

13. A transformer/reactor according to any of the preceding claims, **characterized** in that the shell (12) is wound by a band (6) of the magnetizable material covered by glue or paste (10).

14. A transformer/reactor according claim 13, **characterized** in that the glue or paste (10) on the band (6) of magnetizable material comprises a curable resin.

15. A transformer/ reactor according to any of the claims 13-14, characterized in that the glue or paste (10) comprises a magnetizable filling agent, such as iron powder or magnetite powder.

5 16. A transformer/reactor according to any of the preceding claims, characterized in that the winding (4) is surrounded by a support construction (2).

10 17. A transformer/reactor according to claim 16, characterized in that the support construction is formed as a tube (2).

15 18. A transformer/reactor according to the claims 16 or 17, characterized in that the support construction (2) is formed by an insulating material, such as a plastic material.

19. A transformer/reactor according to any of the claims 16-18, characterized in that the support construction (2) and the shell (12) are torus-shaped.

20 20. A transformer/reactor according to any of the preceding claims, characterized in that openings (14, 16; 18, 20) are performed through the shell (12) in to the winding (14) for electrical through-connections and for supply and removal of a cooling medium.

25 21. A transformer/reactor according to any of the preceding claims, characterized in that two adjacent openings (18, 20) are formed through the shell (12) for supply and removal of a cooling medium and in that a perforated partition wall (22) for the passage of the winding cable is arranged between the openings substantially across the winding space
30 inside the shell.

22. A transformer/reactor according to any of the preceding claims, **characterized** in that cooling tubes are inserted in parallel with the cable into the winding (4).

5 23. A transformer/reactor according to any of the preceding claims, **characterized** in that the cooling medium for cooling the electric winding (4) is air, a liquid or a cryo-liquid, such as liquid nitrogen or liquid CO₂.

10 24. A transformer/reactor according to any of the preceding claims, **characterized** in that the transformer/reactor is formed for operating in the voltage range 36-800 kV.

15 25. A multi-phase shell transformer/reactor, **characterized** in that a plurality of transformers/reactors according to any of the preceding claims are arranged to jointly form a multi-phase transformer/reactor.

20 26. A method for producing a shell transformer/reactor comprising at least one electric winding (4) surrounded by a shell (12) of a magnetizable material, **characterized** in that the electric winding (4) is wound in a support construction (2) and includes an electric high voltage cable (11), which is arranged to substantially enclose an electric field generated by a current in the winding.

25 27. A method for producing a shell transformer/reactor according to claim 26, **characterized** in that the shell (12) is wound on the outside of the support construction (2) by a band (6) of a magnetizable material.

30 28. A method according to claim 27, **characterized** in that a glue or paste (10) is applied on the band (6) before the winding operation in order to glue or paste the turns of winding together to a rigid shell (12).

29. A method according to claim 27 or 28, **characterized** in that pins or blocks are arranged in a direction through the shell (12) to be formed at the winding of the shell at those positions, where openings (14, 16; 18, 20) through the shell are desired for electrical through-connections and cooling tubes, whereupon the band (6) of magnetizable material is wound on the side of said pins or blocks, and the pins or blocks thereafter are removed.

30. A method according to any of the claims 26-29, **characterized** in that the primary and secondary windings of the transformer are wound mixed with each other.

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Fig. 1

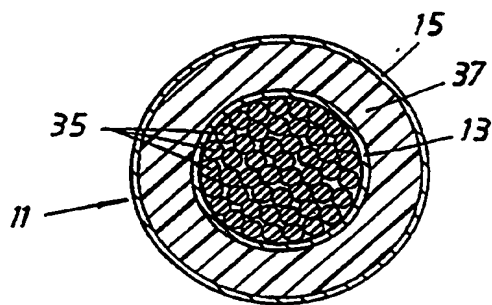


Fig. 2

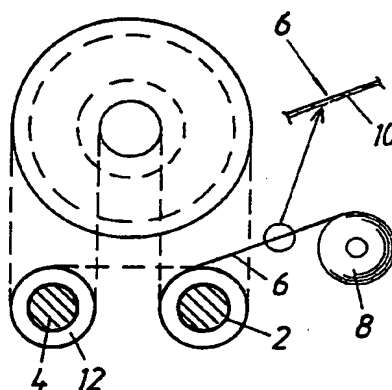


Fig. 3

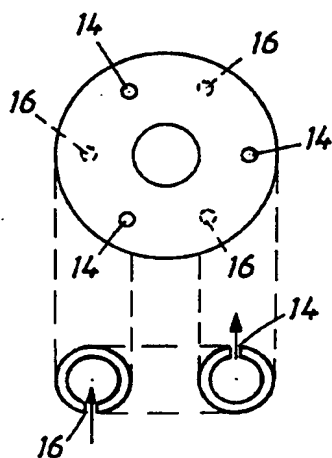
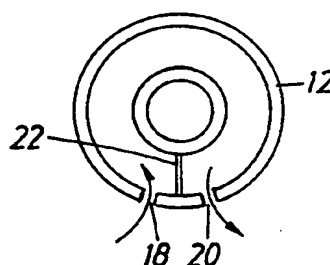


Fig. 4



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